

COUNTER-DIFFUSION IN A WETTED WALL COLUMN

BY

ROBERT LAMAR PIGFORD

B.S., Mississippi State College, 1938

M.S., University of Illinois, 1940

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN
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Introduction: The wetted wall apparatus has been used frequently in theoretical investigations of diffusional processes, such as gas absorption, humidification, and extraction. Other types of equipment give more efficient contact between the vapor and liquid streams, but only in such a tower is the actual interfacial area known and can the flow characteristics of the vapor and liquid streams be analyzed with some degree of accuracy. Theoretical studies of the fundamental processes occurring in distillation have been complicated by the fact that flowing surfaces, bubble surfaces, and drop surfaces existed in the apparatus. By using a wetted wall for fractionation, the rate of mass transfer across a flowing surface may be investigated without contribution from the other two types of surfaces. Distillation differs from other diffusional processes in that simultaneous counter-transfer of two or more diffusing components takes place. The effects of this complication on the action in a wetted wall column apparently have not been studied experimentally.

In the present investigation the effects of composition and fluid velocities on the rate of mass transfer in a small wetted wall column were studied in the distillation of the four systems benzene-toluene, toluene-ethylene dichloride, ethanol-water, and acetone-chloroform. In addition, the apparatus was operated as an absorption column in which pure toluene vapor was absorbed by liquid ethylene dichloride, and ethylene dichloride vapor was absorbed by benzene. The results indicate the relative values of the resistances in the liquid and vapor phases to diffusion.

Apparatus and Experimental Procedure: The apparatus consisted of a wetted wall fractionating section six feet long and 1.17 inches in internal diameter. The column was insulated electrically to insure adiabatic operation. The reflux was heated electrically to the boiling point. Various piping connections, a small reflux pump, and a reflux storage tank were provided for operation as an absorption column.

Material and heat balances were made possible by measurements of vapor and liquid rates and analyses of vapor and

liquid samples.

Distillation at Total Reflux: Experimental values of the overall resistance to transfer of material were calculated from the data in terms of H.T.U., a quantity introduced by Chilton and Colburn.¹ As a part of the overall resistance occurs in each phase, the overall resistance may be divided into two parts according to the following relation, due to Colburn.²

$$(\text{H.T.U.})_{\text{OV}} = (\text{H.T.U.})_{\text{V}} + (\text{H.T.U.})_{\text{L}} (\bar{m}V/L) \quad (1)$$

The quantities $(\text{H.T.U.})_{\text{V}}$ and $(\text{H.T.U.})_{\text{L}}$ depend on the Reynolds numbers of the vapor and liquid phases, respectively. At total reflux the quantity $(\bar{m}V/L)$ depends only on the average composition. The variation in $(\text{H.T.U.})_{\text{OV}}$ with composition at constant values of the vapor and liquid Reynolds numbers indicate the magnitude of $(\text{H.T.U.})_{\text{L}}$, which is proportional to the resistance in the liquid phase.

On this basis, the data on four systems studied at total reflux indicate that $(\text{H.T.U.})_{\text{V}}$ is more than ninety percent of $(\text{H.T.U.})_{\text{OV}}$. The data are correlated by the equation

$$\frac{(\text{H.T.U.})_{\text{OV}}}{d} = 7.63 (\bar{\text{Re}}_{\text{V}})^{0.23} (\text{Sc}_{\text{V}})^{0.67} \quad (2)$$

and agree within ten percent with the von Kármán-Sherwood theoretical equation,⁴ and of Chilton and Colburn,¹ and of Gilliland and Sherwood.³

Operation as an Absorption Column: In order to study the effect of the reflux ratio, L/V , on $(\text{H.T.U.})_{\text{OV}}$, the apparatus was operated as an absorption column, boiling one pure component and introducing the other as reflux. The results on ethylene dichloride-toluene showed a considerable variation of $(\text{H.T.U.})_{\text{OV}}$ with $(\bar{m}V/L)$. This is explained by the fact that in this case a considerable quantity of the liquid was vaporized as it flowed down the column, thus causing the transfer into the liquid stream of less of the less volatile component than would be transferred in the usual case of distillation at total reflux.

Because the boiling points of ethylene dichloride and benzene are much closer together than are the boiling points of toluene and ethylene dichloride, the data for the first pair of these materials agrees with the correlation expressed in Equation (2). The observed values of $(H.T.U.)_L$ were less than ten percent of $(H.T.U.)_{OV}$, and were only about one-tenth as great as values calculated from a theory based on diffusion of the components through a laminar liquid layer. This discrepancy is attributed to the effects of the ripples which were observed at the interface throughout the investigation, and of the counterflow of the vapor.

The effect of the counter-diffusion of the components, as distinguished from diffusion of one component through a second inert component, is negligible under the conditions studied.

TABLE OF NOMENCLATURE

(H.T.U.)	height equivalent to a transfer unit, feet; subscripts OV, V, and L, designate, respectively, an overall value, and values for the vapor and liquid phases
L	liquid rate, moles per unit of time
$\bar{m}$	average slope of the equilibrium curve
$\overline{Re}_V$	average Reynolds number of vapor
Sc_V	Schmidt number of vapor
V	liquid rate, moles per unit of time

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VITA

The author was born in Meridian, Mississippi, on April 16, 1917. He attended the public schools of that city and was graduated from Meridian High School in 1934. In 1938, having completed his undergraduate work, he received a Bachelor of Science degree from Mississippi State College at Starkville, Mississippi. In the fall of that year he entered the Graduate School of the University of Illinois, where he held a University Scholarship and later an appointment as a Graduate Research Assistant in the Engineering Experiment Station of the University. From this university he received a Master of Science degree in 1940. He is co-author of a paper entitled "Heat Transfer to Clouds of Falling Particles", which was published in "Transactions of American Institute of Chemical Engineers, Vol. 37, No. 1, pp. 95-134, February 25, 1941.



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